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The Effectiveness of 90mm Tank Gun Fire Against the 18-Inch Searchlight (U)

by

Allred J Kraemer

FC

U.S. Army Armor Human Research Unit
Fort Knox, Kentucky

Under the Technical Supervision of

The George Washington University
HUMAN RESOURCES RESEARCH OFFICE
operating under contract with
THE DEPARTMENT OF THE ARMY

ASTIA
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ARMTRN

THE EFFECTIVENESS OF 90mm TANK GUN FIRE AGAINST THE 18-INCH SEARCHLIGHT (U)

by

Alfred J. Kraemer

Approved

NORMAN WILLARD, JR.
Director of Research
U.S. Army Armor Human Research Unit
Fort Knox, Kentucky

WILLIAM L. BOYESTON
Lt Col, Armor, Chief
U.S. Army Armor Human Research Unit
Fort Knox, Kentucky

MEREDITH P. CRAWFORD
Director
Human Resources Research Office

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HUMAN RESOURCES RESEARCH OFFICE
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Dr. Howard H. McFann was Director of Research [illegible] U.S. Army Armor Human Research Unit when the study reported here was conducted.

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SUMMARY AND RECOMMENDATIONS

(U) MILITARY PROBLEM

The primary function of the 18-inch tank-mounted searchlight is to provide illumination for aimed main gun fire. How can the light actually be employed in this way without too great a risk that the carrier tank will be destroyed by enemy arms? To answer this question requires an estimate of the maximum effectiveness of enemy main gun fire against a carrier tank. The study summarized here was conducted to provide this estimate, based on the performance of the fire control system of the M48A2 tank.

(U) RESEARCH PROBLEM

The study was an attempt to answer five specific questions:

(1) What are the first-round and total-round hit probabilities for the M48A2 fire control system when fire is aimed at an 18-inch tank-mounted searchlight?

(2) What are the probabilities that the carrier tank will be hit within certain time intervals after its searchlight is turned on?

(3) In this firing situation, is sensing accurate enough to make adjustment of fire possible?

(4) Which are more accurate, sensings made by the tank commander or those made by observers stationed to the flank of the firing tank?

(5) What training problems are related to firing against searchlights?

(U) RESEARCH METHOD

Target. Since the cost of firing directly at 18-inch searchlights would be prohibitive, a target site was designed which made it possible to fire at a mirror image of the searchlight which was not, for firing purposes, distinguishable from an actual light. The use of large target panels and color-coded rounds made possible the collection of dispersion data.

Equipment. Eight M48A2 tanks with new M41A1 gun tubes, and four 18-inch searchlights with 2,500-watt bulbs, were used.

Subjects. The firing was done by eight tank commanders, two classified by their commanding officers as average, and six as expert. Each tank commander was assigned to one tank, which he fired throughout the study. The proficiency level of the eight loaders was approximately that of the average Advanced Infantry Training (AIT) graduate. Eight crewmen served as sensing observers, stationed to the flank of the firing tanks.

Design of the Experiment. The over-all design may be summarized as follows:

Range (Yards)	Firing Positions for Each Tank	Number of Shot Groups Fired	Maximum Number of Rounds per Shot Group
800	In beam center	8	5
800	Out of the beam	8	5
1,500	In beam center	16	10
1,500	Out of the beam	16	10

SUMMARY AND RECOMMENDATIONS

Each tank commander (each tank) fired one shot group from each of the two 800-yard positions and two shot groups from each of the two 1,500-yard positions. The tank was stationary; the searchlight was rotated 10° so that the tank was out of the beam for half the shot groups. For each shot group, firing was stopped when the maximum number of rounds had been fired, or sooner if the target mirror was destroyed. The tank commander and two observers made sensings for each round fired.

Procedure. An attempt was made to approximate User Service Test conditions, as outlined in Report R-1380A, Frankford Arsenal. Since night firing conditions are not described in that report in sufficient detail to permit operational duplication, arbitrary interpretations were made in establishing the firing procedures to be followed in this study.

Firing positions were selected which were as level as possible and from which the angle of site was as near to zero as possible. All rounds were APT-T33E7 ammunition and were fired from the tank commander's station. During the afternoon of each firing night, tanks were zeroed for each shot group.

For all the shot groups fired from 800 yards, the correct range was indexed in the fire control system. For the first half of the shot groups fired from 1,500 yards, the tank commander was required to range on the target; for the second half, selected ranges were indexed, representative of the ranging errors which can be expected under these firing conditions.

Ammunition from the same lot was used throughout the test, except on the last night. Firing was conducted only under certain specified weather conditions.

(C) MAJOR FINDINGS

First-Round Hit Probabilities. Data were obtained for three target areas: the mirror (18 inches square as a target); a section of the target panel 7 1/2 feet square, with the mirror as its center; and a lower central section of the target panel representing the carrier tank. The first-round hit probabilities (both beam positions combined) were:

Range	Mirror Target	Target 7 1/2 Feet Square	Carrier Tank Target
800 yards	.06	1.00	.88
1,500 yards	0	.41	.25

Hit Probability as a Function of Time. At 800 yards, hit probability for one tank which opened fire on a carrier tank as soon as the searchlight was turned on was .50 in 25 seconds—that is, in approximately the time it took, on the average, to fire the first round. For two tanks firing, the hit probability was .75 within 25 seconds.

At 1,500 yards, hit probabilities were .39 for two tanks and .53 for three tanks in 40 seconds, the average time required to fire the first round at that range.

Effects of Practice. Hit probability for the first half of the shot groups fired from 1,500 yards was .48; for the second half of the 1,500-yard firing, it was .76. The average time required to get a hit was reduced, for the second half of test firing, by 28 per cent at 800 yards and by 20 per cent at 1,500 yards. There is no evidence that sensing improved with practice.

SUMMARY AND RECOMMENDATIONS

Sensing Performance. At all the positions from which sensings were made, performance was much better than would be expected by chance. The results show that for rounds fired from beam center, sensings made from a position to the flank of the firing tank were more accurate. For rounds fired from outside the beam, sensings made by the tank commander were more accurate.

(C) CONCLUSIONS

Two assumptions must be made before the results of the study become acceptable as an estimate of the effectiveness of enemy tank gun fire against the 18-inch tank-mounted sear hlight. It must be assumed that the performance of enemy medium gun tanks is comparable to that of the M48A2 tank. Also it must be assumed that a firing test carried out under User Service Test conditions is appropriate for estimating the maximum capabilities of the enemy in combat.

(1) At both ranges (800 and 1,500 yards), and presumably at ranges between them, the risk of destruction of the carrier tank is considerable if the searchlight remains on long enough to enable enemy tanks to fire.

(2) When the searchlight is used to provide illumination for delivering aimed main gun fire against enemy armor, the light should not be turned on for as long a period as it takes enemy tanks to get off a first round each. (Average times to fire the first round, in this study, 26 seconds at 800 yards; 39 seconds at 1,500 yards, including ranging time.) For a tank platoon equipped with two searchlights, the action suggested is that the lights be turned on in succession to illuminate the same target area, leaving each light on for a period slightly shorter than that needed by enemy tanks to fire; and that each carrier tank be moved as soon as its light is turned off. This will illuminate the target for a period twice as long as that during which each carrier tank is a target for enemy fire.

(3) Firing against searchlights seems to be a unique gunnery task which requires practice in addition to that afforded by conventional gunnery exercises.

(U) RECOMMENDATIONS

(1) That the findings and conclusions from this study be incorporated into armor doctrine and literature pertaining to searchlights.

(2) That tank platoon training for night combat emphasize training in coordinated action between carrier tanks and firing tanks.

(3) That tank commanders be given practice in firing against searchlights if the use of searchlights by enemy armor is anticipated; and that the target layout designed for this study be utilized in such firing practice.

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DESCRIPTION
OF THE RESEARCH

THE EFFECTIVENESS OF 90mm TANK GUN FIRE AGAINST THE 18-INCH SEARCHLIGHT (U)

(U) PROBLEM

One result of the efforts in recent years to extend the night fighting capabilities of Armor is the development of the 18-inch tank-mounted searchlight. This light has been in use since 1952 but has not yet been widely issued, and methods for its employment have been stated only in general terms.[1] Its chief function is to provide illumination for aimed main gun fire. Methods must therefore be developed to provide adequate illumination of targets and, at the same time, minimize the probability of destruction of the carrier tanks by fire from the main armament of enemy tanks.

Such methods cannot be developed without an estimate of the maximum effectiveness of enemy main gun fire against our carrier tanks. The primary objective of this study was to provide such a maximum estimate, basing it on the effectiveness of the main gun of the M48A2 tank against the 18-inch tank-mounted searchlight. The data from this study may also be regarded as providing an estimate of the effectiveness of our tanks against similar enemy searchlights. A secondary objective, then, was to obtain information which might be used to improve methods of firing against searchlights.

To accomplish these aims, the study was designed to determine:

(1) The first-round and total-round hit probabilities for the M48A2 fire control system when fire is aimed at an 18-inch tank-mounted searchlight.

(2) The probabilities that the carrier tank will be hit within certain time intervals after its searchlight is turned on.

(3) Whether, in this firing situation, rounds can be sensed accurately enough to make adjustment of fire possible.

(4) Whether sensing is more accurate from positions to the flank of the firing tank or from the firing tank itself.

(5) Training problems related to firing at searchlights.

RESEARCH METHOD

(U) Approach

Test firing against a searchlight with the main gun of a tank presents a number of problems:

(1) When several hundred test rounds are to be fired, the light must be protected from damage; otherwise the cost of the test would be prohibitive.

[1] *Employment of the 18-Inch Tank-Mounted Searchlight in Battlefield Illumination*, D A Training Circular 17-2. (Reference 4.)

(2) The location of each round at or near the plane of the target must be recorded on a target panel so that dispersions can be computed. At a range of 1,500 yards, a panel at least 20 feet square is required.

(3) The sequence of the rounds in a shot group must be identifiable on the panel. (It is not possible to spot the rounds at night, since the target panel is not visible.)

(4) The effects of the searchlight glare must be minimized. When fire is directed against a searchlight from positions near the center of the beam, the gunner is faced with an uncomfortable glare in his periscope sight, which may make precise laying and sensing difficult.

These four problems were solved in the following ways.

(1) If only first-round hit probabilities were involved, the light could be protected by the simple device of sighting at the light and actually firing at a panel target beyond it, using a known elevation offset. When subsequent rounds are to be fired with adjustment, however, each round must be aimed directly at the light to enable the tank commander (or gunner) to change his lay on the basis of his sensing of the previous round. Therefore, a special target site was designed which protected the light from damage, yet kept it visible as a target. (See Figure 1.) The light was buried in a trench which was dug at the top of a berm. The light faced in the direction of fire and its beam was reflected toward the firing site by two plate glass mirrors.

(2) Two target panels were erected to collect the rounds fired at the image of the light. One was located behind the trench, the other in front of the berm. The dimensions and the relative positions of the target components are shown in Figure 1. The panels were made of cardboard covered with target cloth, and were supported by wooden

SEARCHLIGHT TARGET

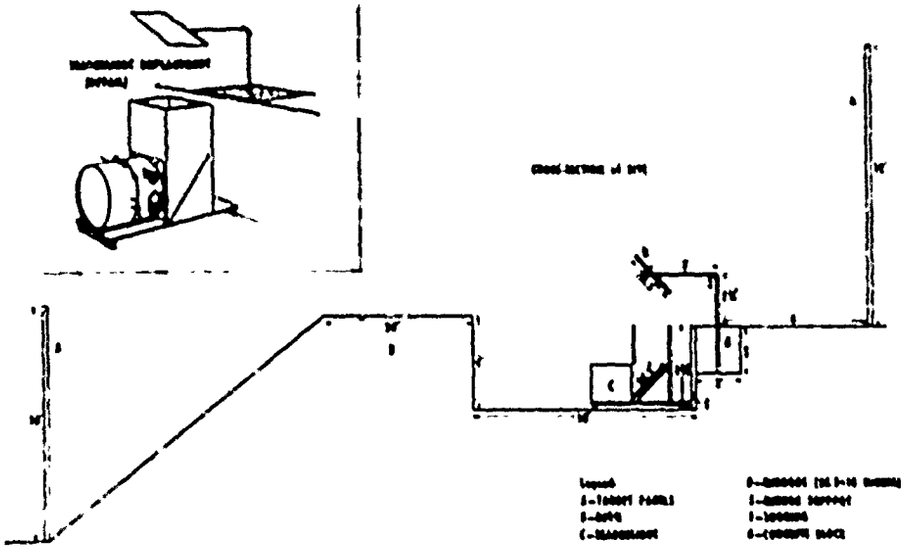

Figure 1 (U)

frames. The alignment of the upper mirror and the panels was such that, as seen from the firing position, the target site looked almost like a single panel target 20 feet square with an 18-inch square mirror at its center. (See Figure 2.) During the test firing only the image of the searchlight was visible. Four such target sites were constructed to make it possible to fire four shot groups per night without delay for target repair.

TARGET SITE AS SEEN FROM FIRING POSITION

Figure 2 (U)

(3) Identification of the holes in the target panels was made possible by color-coding the ammunition. The nose cone of each round in a shot group was painted a different color with spray enamel, which left an acceptable trace on the target cloth. Thus all first rounds left one kind of trace, all second rounds left another, and so on.[1]

(4) All firing was done from the tank commander's position; the range finder was used as the firing sight and glare was minimized by the neutral density filter of that instrument.

[1]Two colors were used on some rounds in the sequence to avoid using less suitable colors. The following sequence of colors was used: 1) red, 2) blue, 3) yellow, 4) green, 5) orange, 6) blue-red, 7) yellow-green, 8) red-green, 9) light blue, 10) copper.

(U) Equipment

Four 18-inch searchlights (Strong Electric Corporation Model 9800-A), each equipped with a 2,500-watt bulb (General Electric Model 2500T30), were used as target lights. They were activated by two auxiliary generator and engine assemblies, each duplicating the auxiliary electrical system of the M48A2 tank.

Eight M48A2 tanks equipped with new 90mm gun tubes (M41A1) were used. Their fire control instruments had been inspected by the Ordnance Fire Control Instruments Shop, Fort Knox, and passed as being in satisfactory condition. (Each tube had fired three Ordnance check rounds.)

(U) Subjects

The firing was done by eight tank commanders stationed at Fort Knox. Two were from the Combat Vehicle Section, U.S. Army Armor Board, one from the 6th Armored Cavalry Regiment, one from the 30th Tank Battalion, and four from the 894th Tank Battalion. Six were classed by their commanding officers as "expert" gunners; the other two were classed as "about average." Each was assigned to one tank, which he fired throughout the test.

Eight loaders were used. Their level of proficiency was about that of the average AIT graduate ("expert" loaders could not be obtained). Six remained with the same tank throughout the test, but two had to be replaced for some shot groups.

Eight other tank crewmen served as scoring observers at positions to the flank of the firing tanks.

(U) Design

The eight tanks fired a total of 48 shot groups from two ranges, with the beam in two positions at each range. As shown in Table 1, the ranges were 800 and 1,500 yards.[1] The firing positions (at each range) were (1) at the center of the searchlight beam and (2) out of the beam, at 10° from beam center. Tanks remained stationary; in-beam firing positions were converted into out-of-beam firing positions by a 10° rotation of the searchlight.

Eight shot groups (maximum, 5 rounds each) were fired from each 800-yard position, and 16 (maximum, 10 rounds each) from each 1,500-yard position. Each tank commander fired one shot group from each 800-yard position and two shot groups from each 1,500-yard position, a total of six shot groups for each tank. Table 2 shows the sequence of firing positions for each tank. One shot group was fired from each of four tanks on each firing night.

Each shot group was terminated when the target mirror was destroyed or when the maximum number of rounds had been fired,

[1]Actual ranges were within 10 yards of the target distances.

Table 1 (U)

OVER-ALL DESIGN OF THE EXPERIMENT

Range	Firing Position	Number of Shot Groups	Maximum Number of Rounds per Shot Group
800 Yards	In beam center	8	5
	Out of the beam	8	5
1,500 Yards	In beam center	16	10
	Out of the beam	16	10

Table 2 (U)

SCHEDULE FOR SHOT GROUPS FIRED BY THE EIGHT TANKS[a]

Firing Night	Shot Group, Range, and Firing Position[b]			
	Tank I	Tank II	Tank III	Tank IV
1	1. 800 In	2. 800 Out	3. 1,500 In	4. 1,500 Out
3	9. 1,500 Out	10. 1,500 In	11. 1,500 In	12. 1,500 Out
5	17. 1,500 Out	18. 1,500 In	19. 800 Out	20. 800 In
7	25. 800 Out	26. 800 In	27. 1,500 Out	28. 1,500 In
9	33. 1,500 In	34. 1,500 Out	35. 1,500 Out	36. 1,500 In
11	41. 1,500 In	42. 1,500 Out	43. 800 In	44. 800 Out
	Tank V	Tank VI	Tank VII	Tank VIII
2	5. 800 In	6. 800 Out	7. 1,500 In	8. 1,500 Out
4	13. 1,500 Out	14. 1,500 In	15. 1,500 In	16. 1,500 Out
6	21. 1,500 Out	22. 1,500 In	23. 800 Out	24. 800 In
8	29. 800 Out	30. 800 In	31. 1,500 Out	32. 1,500 In
10	37. 1,500 In	38. 1,500 Out	39. 1,500 Out	40. 1,500 In
12	45. 1,500 In	46. 1,500 Out	47. 800 In	48. 800 Out

[a]The following changes had to be made: shot groups 2 and 4 were fired on a make-up night (after the sixth night); shot group 27 was fired in the place of 38; shot groups 30, 32, 38, and 39 were fired on a make-up night (after the last scheduled test night). These changes were due mostly to extensive difficulties, and did not involve changes in gunners or tanks.

[b]The numerals indicate range in yards. "In" and "out" indicate the firing position, inside or outside the searchlight beam.

whichever occurred first.[1] It was possible to destroy the mirror by three kinds of hits: (1) a direct hit; (2) a hit on the two-inch supporting pipe, 12 inches of which was exposed between the berm and the mirror; and (3) a ricochet hit (a hit by a round which grazed the top of the berm and bounced into the mirror).

Each round was sensed by the tank commander and by two observers stationed to the flank of the firing tank. The eight observers were rotated systematically through these two observer positions. For shot groups fired from 800 yards, the observer positions were 25 and

[1]One 1,500-yard out-of-beam shot group was terminated after eight rounds because of damage to the *lower* mirror caused by debris from a near miss.

50 yards to the right of the firing position. For shot groups fired from 1,500 yards, they were 50 and 100 yards to the left of the firing position.

PROCEDURE

Test Conditions

(C) In general, the study was intended to approximate User Service Test conditions, as outlined in Frankford Arsenal Report R-1380A, which attempts to specify standard conditions for various types of evaluations of accuracy in tank gunnery.[1] Because the report does not describe firing conditions in sufficient detail for operational use, particularly with reference to night firing, arbitrary interpretations were necessary in formulating the procedures to be used in this study.

(U) Three days before the scheduled test firing began, all personnel went through a practice run, which included zeroing. The entire test procedure was followed, except that each tank fired one shot group of five rounds from 1,000 yards.

(U) For each shot group the fire control system was zeroed about two hours before sundown. The zeroing procedure in Field Manuals 17-12 and 17-79[2] was followed, except that all firing was done from the tank commander's position. The zeroing range was 1,430 yards. Each tank was moved a few hundred yards from the zeroing position to the firing position, which had been selected to be as level as possible, and to have a minimum angle of site.[3]

(U) APT-T33E7 ammunition from the same lot was used for all zeroing and test firing except on the last night of testing. An Army-wide recall of all 90mm AP ammunition occurred before the final test night; ammunition from another lot was subsequently used for the night on which shot groups 30, 32, 35, and 38 were fired.

(U) Test firing began about two hours after sundown. Just before being moved to its firing position, each tank was supplied with the maximum number of ammunition rounds (five rounds for 800 yards, 10 rounds for 1,500 yards). The color-coded rounds were placed in the ready rack in the predetermined order in which they were to be fired. Shot groups were fired one at a time in the order shown in Table 2. Only one tank was stationed at a firing site at any time. All test firing was done from the tank commander's position.

(U) The tank commanders and loaders were instructed to try to obtain a hit on the light as fast as they could. In order to motivate them to

(C) [1]Reference 1. This document reflects the official position of the Office of the Chief of Ordnance. It is expected that, after minor revision, it will reflect the official CONARC position.

[2]References 2 and 3.

[3]From the zeroing position to the 800-yard position the distance was about 1,200 yards; to the 1,500-yard position, about 500 yards. Neither a perfectly level firing position nor zero angle of site is required under User Service Test conditions. Actual angle of site was 20 mils from the 800-yard position and 12 mils from the 1,500-yard position.

operate at maximum speed consistent with good laying, awards were made for hits, the value of each award depending on the time it took to obtain the hit.

(U) Firing Procedure

The following firing procedure was adhered to:

(1) At the firing site, the tank to be fired was pointed in the general direction of the target.

(2) For all shot groups fired from 800 yards, and for the first half of those fired from 1,500 yards, the tank commander indexed battle-sight range (800 yards). For the second half of the 1,500-yard shot groups, a range unknown to the tank commander was indexed. The distribution of these ranges was based on data obtained in an earlier study of ranging against the tank-mounted searchlight.[1] The distribution was normal, with a mean of 1,500 yards and a standard deviation of 191 yards.[2]

(3) For all shot groups fired from 1,500 yards, the range finder range scale and the computer range dial were covered with tape.

(4) The target searchlight was turned on, the tank commander switched the range finder filter lever to the ON position, laid the gun on the light, and then deflected the gun 540 mils to the left. The light was then turned off.

(5) The tank commander took position in his cupola. The loader was ready to pick up the first round.

(6) The target light was turned on again, now as a signal to commence fire, and the tank commander made a gross lay with his periscope sight. The loader loaded the first round on command from the tank commander, then continued loading until all rounds were fired or until he heard a sensing of "target" from the tank commander.

(7) For all shot groups fired from 800 yards and for the second half of those fired from 1,500 yards, the tank commander followed his gross lay with a precise lay with the gun-laying reticle of the range finder, and then fired.[3] For the first half of the shot groups fired from 1,500 yards, the tank commander first ranged on the target light before making his precise lay.

(8) The tank commander announced his sensing of each round, then adjusted his sight picture for the next round by the burst-on-target method. If he sensed the round as "lost," he used the same sight picture in firing the next round.

For all shot groups fired from 800 yards, as previously stated, the correct range was indexed in the fire control system. The procedure used for the 1,500-yard firing was the result of the following circumstances: For the first half of the shot groups fired from 1,500 yards, the tank commander was required to range on the target. It was

[1]Reference 7.

[2]See Appendix A for the individual range values used.

[3]The tank commanders were permitted to adjust the brightness of the ranging reticle in order to make the gun-laying reticle more distinct. Most of them preferred maximum brightness of the ranging reticle for this purpose. They were not permitted to use the auxiliary reticle for laying the gun.

originally planned to follow the same firing procedure for all shot groups fired from 1,500 yards—with the range finder range scale and the computer range dial covered—in effect, forcing the tank commander to range on the target even though he might know the approximate or even the exact range.[1] However, once a tank commander knows the range and the approximate range finder knob position for that range, it is difficult for him to make an honest ranging, even if he wants to.

After close observation of the tank commanders during the first few shot groups fired from 1,500 yards, it was suspected that some of them went through the motions of ranging but were actually attempting to turn the range knob to the 1,500-yard position. When they themselves confirmed this suspicion, it was decided to change the ranging procedure for the second half of the 1,500-yard shot groups. Consequently, for these shot groups, selected ranges not known to the tank commanders were indexed. These ranges were representative of those which can be expected under the firing conditions of this study.

(U) Weather Limitations

Zeroing and test firing were limited to the following weather conditions:

(1) No precipitation.

(2) Temperature 30 degrees Fahrenheit or above, and no drop of more than 20 degrees between zeroing and test firing.

(3) No fog.

(4) Wind velocities no greater than 10, 15, and 20 knots, respectively, at angles of 61-90, 31-60, and 0-30 degrees to the line of fire.

These weather limitations are stricter than those outlined for User Service Test conditions in Frankford Arsenal Report R-1380A. Firing was conducted only under these conditions, although zeroing for one shot group was done during a light snow.

Because of dust at the target site (due to low rounds), and because of obscuration, the visibility of the target dropped considerably during some shot groups. However, because of the nature of the target, low target visibility was never a problem to the tank commander. In fact, for shot groups fired from the center of the beam, periods of lower visibility undoubtedly made gun laying easier.

RESULTS

(U) Data Analysis

A total of 268 test rounds were fired, 57 from 800 yards and 211 from 1,500 yards. All rounds fired from 800 yards and all but 16 of

[1]Other ways of forcing the tank commander to range were found to be either not feasible or not adequate. It was not possible to place targets at unknown distances bracketing 800 and 1,500 yards, for the target installation was permanent and the four target sites were located at the only berm on the range. Moving tanks to another firing site for each shot group was not considered an adequate procedure, since some of the tank commanders were familiar with the dimensional characteristics of the range facilities.

those fired from 1,500 yards passed through the area covered by the target panels (20 feet square).

The coordinates for every round were measured from photographs of the panels, or from the target cloths directly.[1] For each of the 16 rounds which passed outside the panels, coordinates were established as follows: The sensings for the round were checked, and the sensing made at the position which had yielded the best average sensing score for that firing position was accepted as valid.[2] If the round was sensed as "right," for example, it was arbitrarily scored as being 11 feet to the right of target center. Then the vertical position of the round was arbitrarily assigned the median value of the vertical positions of the other rounds in the same shot group. Similarly, a round sensed as "over" was scored as 11 feet above the target center and was given the median horizontal position of the other rounds in the shot group.

Each round was scored as a hit or a miss on three target areas: (1) The target mirror (18 inches square as a target), (2) an area 7 1/2 feet square with the mirror as its center, and (3) the silhouette of an M48A2 tank serving as carrier tank for the searchlight reflected in the target mirror.[3]

RELATIVE POSITION OF THREE TARGET AREAS USED FOR SCORING

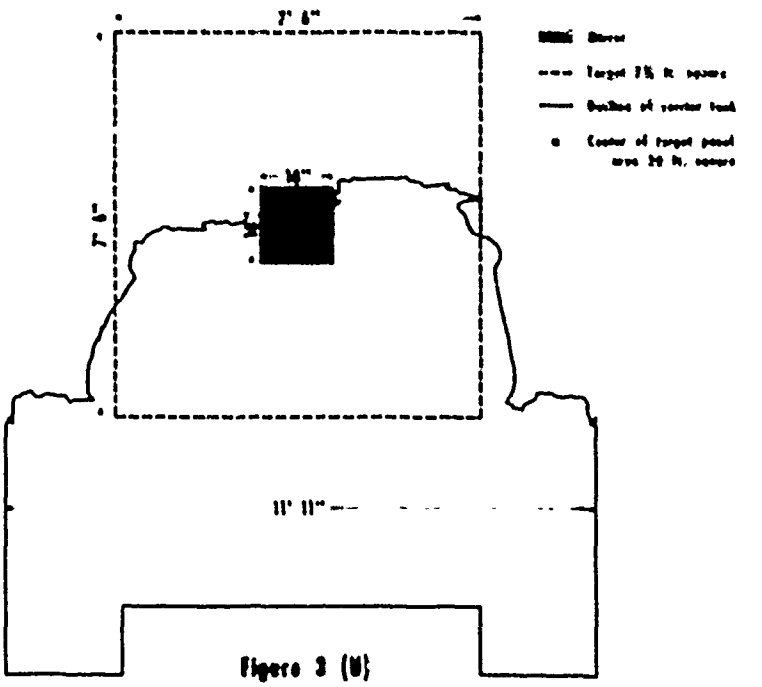

Figure 3 (U)

[1]Photographs of target panels could not be used for all shot groups, because of equipment failure.

[2]None of the 16 rounds was sensed as "lost."

[3]Except as noted later, three hits high on the mirror portion of the target were not scored as hits on the carrier tank target.

Analysis of the first-round vertical dispersion data showed that the change in firing procedure for the second half of the shot groups fired from 1,500 yards did not increase vertical dispersion of first rounds. In other words, requiring the tank commander to fire the first round with typical range error indexed did not increase vertical dispersion over what it had been for shot groups which included some "pseudo-rangings." For this reason, the data for all shot groups fired from 1,500 yards have been combined.

Total Hit Probabilities

(U) Table 3 shows, for all rounds fired, the number of hits and the proportion of rounds resulting in hits (the empirical hit probability, i.e., the ratio of the number of hits to the number of rounds fired). As stated previously, a shot group was terminated when the target mirror was destroyed. Therefore tank commanders who obtained hits on the mirror on earlier rounds fired fewer rounds in those shot groups. It may be assumed that, on the average, they would have fired subsequent rounds as accurately as tank commanders who obtained mirror hits on later rounds. (See Appendix B for total-round dispersion values.)

Table 3 (C)

NUMBER OF HITS AND EMPIRICAL TOTAL-ROUND HIT PROBABILITIES*

Firing Position	Number of Rounds Fired	Target Area					
		Mirror		Panel 7 1/2 Feet Square		Center Tank	
		Hits	Hit Prob.	Hits	Hit Prob.	Hits	Hit Prob.
At 800 Yards							
In Beam Center	32	1	.03	25	.78	21	.66
Out of Beam	25	5	.20	25	1.00	22	.88
Total	57	6		50		43	
Mean Hit Probability			.12		.89		.77
At 1,500 Yards							
In Beam Center	107	5	.05	67	.63	57	.53
Out of Beam	104	8	.08	62	.60	35	.34
Total	211	13		129		92	
Mean Hit Probability			.06		.61		.44
Total for All Firing	268	19		179		135	
Over-All Mean Probability			.09		.75		.60

*Ratio of the number of hits to the number of rounds fired.

First-Round Hit Probabilities

(U) First-round hit probabilities—both empirical and constructive—are shown in Table 4. A "constructive probability" is obtained by estimating,

Table 4 (U)

EMPIRICAL AND CONSTRUCTIVE[a] FIRST ROUND HIT PROBABILITIES

Firing Position	Number of First Rounds	Target Area: Mirror		Panel 2 1 2 Feet Square		Carrier Tank	
		Hit Prob.	SE[b]	Hit Prob.	SE	Hit Prob	SE
At 800 Yards							
In Beam Center	8						
Empirical		12	12	1.0	0	75	16
Constructive		14	.14	95	.09	.68	19
Out of Beam	8						
Empirical		0	0	1.0	0	1.0	0
Constructive		.03	.07	99	04	99	04
Mean Hit Probability							
Empirical		.06		1.0		.88	
Constructive		.08		.97		.84	
At 1,500 Yards							
In Beam Center	16						
Empirical		0	0	.38	.12	.25	.11
Constructive		02	.04	31	.12	38	.13
Out of Beam	16						
Empirical		0	0	.44	.13	.25	.11
Constructive		.02	.04	.34	.13	.35	.13
Mean Hit Probability							
Empirical		0		.41		.25	
Constructive		.02		.32		.36	
Total First Rounds	48						
Over-All Mean Probability							
Empirical		03		.70		.56	
Constructive		.05		.65		.60	

[a]Proportion of hits to be expected, based on population values for center of impact and dispersion.
[b]Standard Error.

from the sample values, the population values for center of impact and for dispersion, and then calculating from these estimates the proportion of hits to be expected.[1] For the carrier tank target, constructive hit probabilities were calculated by simplifying the tank outline to two rectangular target areas (11'11" x 5'5" and 7'6" x 3'3") representing, respectively, the chassis and the turret.

(U) Although empirical probabilities give an accurate picture of the results in terms of number of hits, constructive probabilities, by taking dispersion into account, provide a better estimate of the number of

[1]This calculation assumes that the horizontal and vertical distributions of the population of rounds (in this case, first rounds) are normal distributions.

hits which can be expected in future firings under similar conditions. Considering the small size of the samples used in this study, the correspondence between empirical and constructive probabilities is surprisingly high.

(U) Table 5 shows constructive first-round hit probabilities computed without bias, that is, with the center of impact of the group of first rounds superimposed on the target center. These data represent estimates of the hit probabilities which would be obtained if all horizontal and vertical bias were eliminated. (See Appendix B for first-round center of impact and dispersion values.)

Table 5 (C)

CONSTRUCTIVE FIRST-ROUND HIT PROBABILITIES
ADJUSTED TO EXCLUDE BIAS

Firing Position	Number of First Rounds	Target Area					
		Mirror		Panel 7 1/2 Feet Square		Carrier Tank	
		Hit Prob.	SE	Hit Prob.	SE	Hit Prob.	SE
At 800 Yards							
In Beam Center	8	.21	.17	.97	.07	.53	.20
Out of Beam	8	.52	.20	1.00	.00	.60	.20
Mean Hit Probability		.36		98		.56	
At 1,500 Yards							
In Beam Center	16	.03	.05	.37	.13	.37	.13
Out of Beam	16	.03	.05	.39	.13	.39	.13
Mean Hit Probability		.03		.38		.38	
Total First Rounds	48						
Over-All Mean Probability		.20		.68		.47	

(C) Time Required to Obtain a Hit

Because the tank commanders did not range for the second half of the shot groups fired from 1,500 yards, their time scores for these shot groups were adjusted as follows, to include ranging time: For the first half of the shot groups fired from 800 yards, the median first-round time was 30 seconds; for the first half of those fired from 1,500 yards it was 43 seconds. The difference, 13 seconds, was attributed to ranging, and was therefore added to the time scores of those shot groups fired from 1,500 yards which did not include ranging. Over-all median times to fire the first round were 26 seconds at 800 yards, and 39 seconds (including ranging time) at 1,500 yards.

Table 6 shows the median times (in seconds) and the median numbers of rounds required to obtain a hit. No data are given for the mirror

target, since more than half the shot groups contained no hits on the mirror. Table 7 gives a more detailed tabulation of the relation [illegible]

Table 6 (C)

MEDIAN TIME AND MEDIAN NUMBER OF ROUNDS REQUIRED TO OBTAIN A HIT*

Firing Position	Panel 7 1 2 Feet Square		Carrier Tank	
	Time (Seconds)	Rounds	Time (Seconds)	Rounds
At 800 Yards				
In Beam Center	22	1	23	1
Out of Beam	28	1	28	1
Mean	25	1	26	1
At 1,500 Yards				
In Beam Center	57	2	66	2.5
Out of Beam	42	2	72	3.5
Mean	50	2	69	3

*No data are given for the mirror target, as more than half the shot groups contained no hit on it.

Table 7 (C)

EMPIRICAL HIT PROBABILITIES AGAINST THE CARRIER TANK, WITHIN VARIOUS INTERVALS AFTER THE SEARCHLIGHT IS TURNED ON*

(Percentage of Tanks Obtaining at Least One Hit Within the Time Period)

Firing Position	Number of Seconds After Light Is Turned on									
	15	20	25	30	35	40	45	50	55	60
At 800 Yards										
In Beam Center										
Hit Probability	.12	.38	.62	.75	.88	.88	.88	.88	.88	.88
Standard Error	.12	.18	.18	.16	.12	.12	.12	.12	.12	.12
Out of Beam										
Hit Probability	0	.25	.38	.75	.75	.75	.75	.75	.75	.75
Standard Error	0	.16	.18	.16	.16	.16	.16	.16	.16	.16
Mean Hit Probability	.06	.32	.50	.75	.82	.82	.82	.82	.82	.82
At 1,500 Yards										
In Beam Center										
Hit Probability				0	.06	.19	.19	.31	.38	.44
Standard Error				0	.06	.10	.10	.12	.12	.13
Out of Beam										
Hit Probability				0	.06	.25	.38	.38	.44	.50
Standard Error				0	.06	.11	.12	.12	.13	.13
Mean Hit Probability					.06	.22	.28	.34	.41	.47
Over-All Mean Probability	.03	.16	.25	.38	.44	.52	.55	.58	.61	.64

*Included are those hits on the target mirror not originally scored as hits on the carrier tank target.

between time and hit probability, with the carrier tank as the target. The data in this table represent the percentages of tanks which had obtained at least one hit within the respective time periods from the moment the searchlight was turned on.

Performance as a Function of Practice

(U) The study was not designed to measure the effects of practice, but some aspects of the data may be examined for indications of such effects. As previously stated, each tank commander fired six shot groups (four from 1,500 yards, and two from 800 yards). These were so distributed that, during each half of the test, each fired two shot groups from 1,500 yards and one from 800 yards. Performance during each half may therefore be taken as a unit of practice.

(U) The empirical total-round hit probabilities for each half of the test are shown in Table 8. There is a strong suggestion that performance for shot groups fired from 1,500 yards improved during the course of the test.[1] Also, the median time for first-round hits for the second half of the test was 28 per cent less for shot groups fired from 800 yards, and 20 per cent less for those fired from 1,500 yards. These apparent practice effects are noteworthy because the amount of practice was rather limited, and because most of the tank commanders had had considerable experience as gunners.

Table 8 (C)

EMPIRICAL TOTAL-ROUND HIT PROBABILITIES FOR THE TARGET 7 1 2 FEET SQUARE AS A FUNCTION OF PRACTICE

Firing Position	First Half of Test			Second Half of Test		
	Rounds Fired	Hits	P	Rounds Fired	Hits	P
At 800 Yards						
In Beam Center	13	10	.77	19	15	.79
Out of Beam	14	14	1.00	11	11	1.00
Total	27	24		30	26	
Mean Hit Probability			.88			.90
At 1,500 Yards						
In Beam Center	83	26	.49	54	41	.76
Out of Beam	57	26	.46	47	36	.77
Total	110	52		101	77	
Mean Hit Probability			.48			76
Total for all Firing	137	76		131	103	
Over-All Mean Probability			.68			.83

[1] A similar analysis for other aspects of the probability data was not practicable because of limited sample size.

Sensing Performance

(U) Since there is no standard system for scoring sensing performance, the following system was devised:

Location of Round on Target Panel	Sensing Score
Within 22 1/2 degrees from the sensing	2
Between 22 1/2 and 45 degrees from the sensing	1
Between 45 and 90 degrees from the sensing	0
Over 90 degrees from the sensing	-1

"Degrees" refers to circular degrees in the plane of the target panel. Sensings of "lost" were given a score of 0. Figure 4 illustrates this scoring system; the four diagrams show how a sensing of "short right" was scored.

(U) Table 9 shows the distribution of scores for sensings made from the tank and from the two observer positions. The data for the two ranges

PROCEDURE USED FOR SCORING SENSINGS

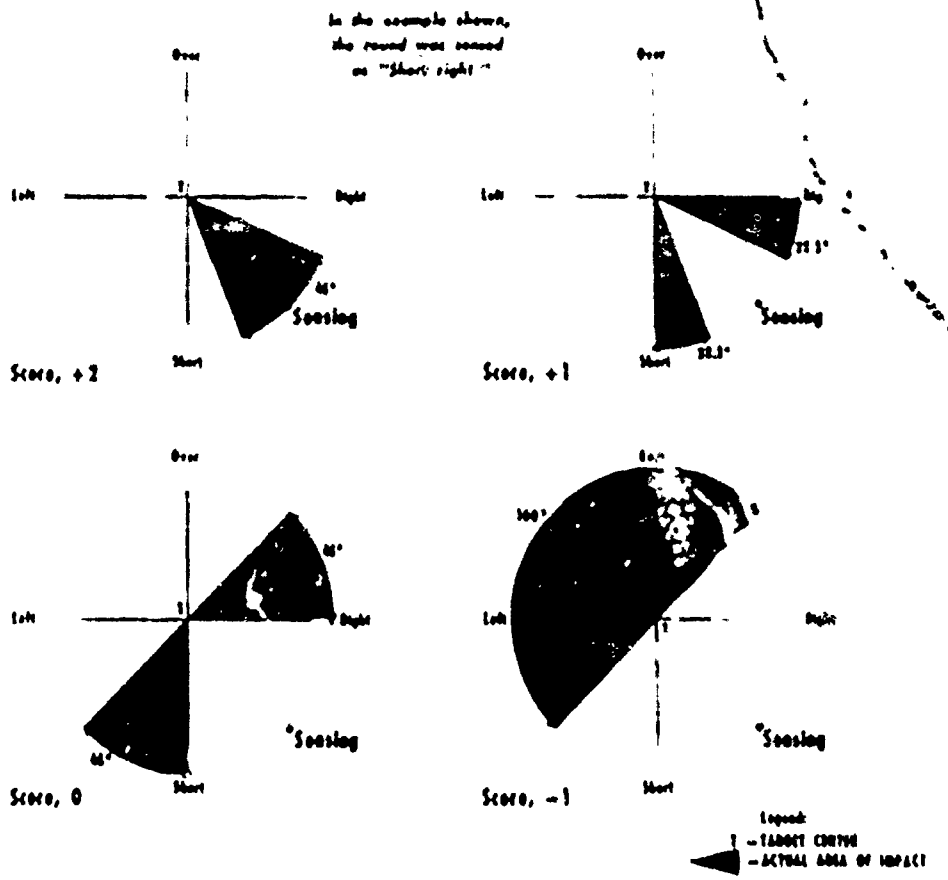

Figure 4 (U)

were combined, since analysis showed no significant variation due to differences in range. At each of the three positions, sensing performance was considerably better than would be expected on the basis of chance alone; all differences were significant well beyond the .0001 level of confidence. More than half the sensings had a score of +1 or +2. Since all rounds had to be sensed with respect to an 18-inch square, and since about 9 per cent of the rounds had tracer failures, these results indicate a considerable degree of accuracy in sensing performance. For rounds which missed the 7 1/2 foot square target area, two-thirds of the sensings had a score of +1 or +2.

Table 9 (C)

NUMBER OF SENSINGS WHICH RECEIVED EACH SCORE, FOR EACH SENSING POSITION

Sensing Score[a]	Sensing and Firing Position					
	Tank Commander		Near Lateral Observer[b]		Far Lateral Observer[c]	
	In Beam	Out of Beam	In Beam	Out of Beam	In Beam	Out of Beam
2	40	44	52	35	42	37
1	16	2[illegible]	19	28	20	24
0[d]	50	24	33	33	35	27
-1	20	13	22	14	29	22
Total Sensings	126	110	126	110	126	110
Total Sensing Score	76	104	101	84	75	76
Mean Sensing Score	.60	.95	.80	.76	.60	.69

[a]See text for chart of scoring system.

[b]For 800-yard firing, the near lateral sensing position was 25 yards to the right of the firing tank, for 1,500-yard firing, 50 yards to the left.

[c]For 800-yard firing, the far lateral sensing position was 50 yards to the right of the firing tank, for 1,500-yard firing, 100 yards to the left.

[d]Included in the sensings given a score of zero are those for rounds sensed as "lost", 15 20 rounds did not show a tracer.

(U) During the course of the study the eight observers made twice as many sensings as the eight tank commanders. A comparison of the sensings made by the observers during the first 24 shot groups with those made during the second 24 shot groups shows that the additional practice by the observers did not result in improved sensings. This lack of improvement was to be expected because the observers had no knowledge of the accuracy of their performance.

(C) According to the sensing data, for rounds fired from positions in the searchlight beam, sensings made from the nearer of the two observer positions were most accurate. For rounds fired from positions out of the beam, sensings made from the tank were most accurate. A Chi square test showed these differences to be significant at the .001 level of confidence.

(C)

DISCUSSION

Before the results of the study can be accepted as answering the problem of estimating the effectiveness of main gun fire from enemy tanks against tanks employing the 18-inch tank-mounted searchlight, two important factors must be considered. First it must be assumed that the effectiveness of enemy medium gun tanks is equivalent to that of the M48A2 tank. Second, it must be assumed that a firing test carried out under User Service Test conditions is appropriate for estimating enemy capabilities under combat conditions.

Hit probabilities noted herein are probably somewhat higher and firing times somewhat lower than would be expected under many, though not necessarily all, combat conditions. Also, it should be noted that hit probabilities against the carrier tank which have been obtained in this study refer to a stationary and fully exposed tank; against a moving tank or against a tank positioned in defilade, hit probabilities would naturally be smaller.[1]

The most relevant aspects of the results are shown in Table 7. At a range of 800 yards, hit probability against the carrier tank rapidly approaches 1.0. It is likely that as soon as its searchlight is turned on, a carrier tank would become a target for more than one enemy tank. With two enemy tanks firing against it, hit probability approaches 1.0 within 25 seconds, that is, within the average time it takes to fire the first round. It may be concluded, then, that at ranges of about 800 yards, the risk of destruction of the carrier tank becomes too great if the searchlight is on long enough to enable two enemy tanks to fire one round each.

A similar analysis shows that at 1,500 yards the number of enemy tanks firing increases in importance as a factor in hit probability. With a single enemy tank firing, hit probability is .22 in 40 seconds after the searchlight is turned on, that is, within the average time it takes to fire the first round at that range. With two enemy tanks firing, probability is .39; and with three tanks, .53. Table 10 shows how various hit probabilities increase as a function of the number of tanks firing. This analysis indicates that even at ranges of about 1,500 yards the risk of destruction of the carrier tank becomes relatively high if each of several enemy tanks is able to fire one round.

If the foregoing analyses were made with respect to a daytime engagement, the conclusions would be regarded as self-evident, and the results reported here would be regarded as proving only the obvious. However, the results of small-arms firing tests against the tank-mounted searchlight[2] seem to have been overgeneralized, and have created considerable doubt about the effectiveness of any fire against the light and the carrier tank. The results of this study should serve to dispel such doubts.

[1]It should be noted that only level terrain would permit target illumination by a moving carrier tank.

[2]References 5, 6, and 8.

Table [illegible]

TABLE OF THEORETICAL HIT PROBABILITIES WITH MORE THAN ONE TANK

Given these theoretical hit probabilities for one tank	These will be the hit probabilities for 2 tanks	3 tanks	4 tanks	5 tanks
05	.10	.14	.18	.23
10	.19	.27	.34	.41
15	.28	.39	.48	.56
20	.36	.49	.59	.67
25	.44	.58	.68	.76
30	.51	.66	.76	.83
35	.58	.72	.82	.88
40	.64	.78	.87	.92
45	.70	.83	.91	.95
50	.75	.88	.94	.97
55	.80	.91	.96	.98
60	.84	.94	.97	.99
65	.88	.96	.98	1.00
70	.91	.97	.99	1.00
75	.94	.98	1.00	1.00
80	.96	.99	1.00	1.00
85	.98	1.00	1.00	1.00
90	.99	1.00	1.00	1.00
95	1.00	1.00	1.00	1.00

The implications of the findings with respect to the employment of the tank-mounted searchlight may be stated as follows: In situations in which the searchlight is to provide illumination for delivering aimed fire from the main gun against enemy armor, the light should not be turned on for as long a period as it takes enemy tanks to open fire. Each of our tank platoons is authorized two searchlights; hence, the lights should be turned on in succession to illuminate the same target area, leaving each light on for a period slightly shorter than that required by enemy tanks to open fire. Each carrier tank should be moved immediately after turning off its light. This procedure will provide illumination of the target area for a period twice as long as that during which each carrier tank is a target for enemy fire. This period is probably long enough to enable each non-carrier tank to fire at least one round at the enemy.

If a period of 25 seconds is accepted as being just short of that required for the enemy to get the first round off, then the suggested searchlight procedure would result in target illumination for about 50 seconds. This is still a relatively short time for finding and engaging an enemy target. Coordinated action between the carrier tanks and the firing tanks therefore becomes all-important. Platoon training for night combat should emphasize this kind of coordination.

The finding that even experienced tank commanders improved their performance suggests that firing against searchlights is a unique gunnery task which requires practice in addition to that afforded by conventional gunnery exercises.

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APPENDICES

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Appendix A (U)

RANGES SET OR INDEXED DURING THE 1,500-YARD FIRINGS

Table A-1

RANGE SETTINGS MADE DURING FIRST HALF OF SHOT GROUPS FIRED AT 1,500 YARDS

Number of Shot Group[a]	Range Setting[b] (Yards)	Number of Shot Group	Range Setting (Yards)
3	1,540	13	1,540
4	1 700	14	1,590
7	1,:30	15	1,495
8	1,100	16	1,850
9	1,480	17	1,550
10	1,500	18	1,500
11	1,550	21	1,480
12	1,150	22	1,570

[a]Shot Groups 1, 2, 5, 6, 19, 20, 23, and 24 were fired at 800 yards.
[b]This distribution of range settings has a mean of 1,505 and a standard deviation of 171.

Table A-2

RANGES INDEXED FOR SECOND HALF OF SHOT GROUPS FIRED AT 1,500 YARDS

Number of Shot Group[a]	Range Indexed[b] (Yards)	Number of Shot Group	Range Indexed (Yards)
27	1,530	37	1,820
28	1,530	38	1,820
31	1,400	39	1,470
32	1,470	40	1,400
33	1,680	41	1,600
34	1,680	42	1,600
35	1,180	45	1,320
36	1,180	46	1,320

[a]Shot Groups 25, 26, 29, 30, 43, 44, 47, and 48 were fired at 800 yards.
[b]This distribution of ranges indexed has a mean of 1,500 and a standard deviation of 191.

Appendix B (C)

SUMMARY OF TARGET DATA

Table B-1

CENTERS OF IMPACT FOR FIRST ROUNDS AND FOR CUMULATIVE ROUNDS

(Mils)

Firing Position	Center of Impact*			
	First Rounds		Cumulative Rounds	
	X	Y	X	Y
At 800 Yards				
In Beam Center	.44	−.29	.40	−.14
Out of Beam	.56	−.68	.35	−.37
Mean	.50	−.48	.38	−.26
At 1,500 Yards				
In Beam Center	.53	−.32	.16	−.16
Out of Beam	.46	.05	.27	.33
Mean	.50	−.14	.22	.08

*A plus X value means right of target center, a minus X value means left. A plus Y value means over target; a minus Y value means short of target.

Table B-2

HORIZONTAL AND VERTICAL DISPERSIONS FOR FIRST ROUNDS AND FOR CUMULATIVE ROUNDS

(Standard deviations in mils)

Firing Position	Dispersion			
	First Rounds		Cumulative Rounds	
	Horizontal	Vertical	Horizontal	Vertical
At 800 Yards				
In Beam Center	.49	.68	.65	1.14
Out of Beam	.43	.22	.46	.62
Mean	.46	.45	.56	.88
At 1,500 Yards				
In Beam Center	.75	1.25	.50	.93
Out of Beam	.47	1.50	.45	1.04
Mean	.61	1.38	.48	.98

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HumRRO Technical Report 56, The Effectiveness of 90mm Tank Gun Fire Against the 18-Inch Searchlight (U), June 1959 (CONFIDENTIAL)

1. On page iii, Summary and Recommendations, under the heading "Research Method" (U), in line 4 of the paragraph titled "Subjects", the word "Infantry" should read "Individual."

2. We would appreciate your making this correction in your copy of the subject report.

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